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Publication date:
2007

Document Version
Publisher's PDF, also known as Version of record

Risø DTU
19 November 2007

Energy innovation and competitiveness indicators
A contribution to Work Package 8 of the MEI project

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A considerable part of eco-innovations is constituted by energy-related technologies, products, and services. Innovation in the energy area is high on the political agenda in many countries. The European Union in its Seventh Framework Programme is expected to increase energy R&D budgets, not only for reasons of energy and climate policy, but also to help increase the EU's overall competitiveness (the "Lisbon Agenda") through initiatives such as the Competitiveness and Innovation Framework Programme (CIP). In this connection competitiveness not only refers to minimizing firms' expenditures to energy but also (and maybe in particular) to industry's ability to innovate and stay competitive within new and sustainable energy technologies. New energy technology is one of very few new technologies where Europe not yet has lost the technological and industrial competition to America and Asia. European firms are the leading industrial actors and Europe has the largest markets in technologies such as wind power, photo voltaics and bio-diesel.

IEA estimates that the cumulative investments in energy supply infrastructure in the reference scenario amounts to 21 trillion USD (21000 billion) in the period 2005-2030. Europe's share of this is 2395 billion USD[1] [2]. Energy is big business, and European policy makers and energy equipment manufacturers have legitimate interests in European firms' innovativeness and competitiveness in this large future market for energy technology.

Innovation can be defined generally as changes in ways of doing things, that generate a value on the market. The process of innovation is often complex and uncertain. It involves both technical and commercial uncertainties and risks. One way to mitigate these risks and uncertainties is to share the innovation process with other stakeholders—not just other companies, but all the different actors that make up the surrounding environment or framework. This means that technological innovation is not solely a matter of technology, manufacturers and markets. Policy makers, analysts and innovators also have to address the wider framework or environment in which companies operate, and in which new innovations and technologies emerge. The concept of an "innovation system" takes this broad view of the process of innovation.

An innovation system can be defined as the elements and relationships which interact in the production, diffusion and use of new and economically useful knowledge (Lundvall, 1992). In this understanding of innovation, the core is knowledge production and learning processes centred on industrial products in companies and markets. The knowledge

[1] World Energy Outlook 2006 (p77)
[2] For comparisons the EU new ambitious energy policy assumes an extra cost of 80 billion EUR in the same period. That equals 3% of the total investments (depending of $/€ exchange rates).

processes are not limited to a single company, but must be seen in a broader institutional context, including not only subcontractors and customers in the product supply chain, but also knowledge networks and knowledge institutions such as universities, research centres, and institutions for innovation support, regulation, and technology diffusion.

In addition to direct indicators of competitiveness like market share, exports, and development in number of companies in the field, the innovation system analyses point to a number of also indirect competitiveness indicators. Among these are for example indicators of knowledge production and competence development and indicators of investments in development activities. Another important group of the indirect indicators of competitiveness are the indicators of co-operation and networks between the actors.

Not least co-operation and interaction between different types of actors and across institutional borders are important as indicators as they show where different kinds of knowledge meet and mutually strengthen each other through their integration. This can for example be between industrial manufacturers and their customers or between the manufacturers and the actors in their supply chain network. Or it can between researchers at public research institutions and private companies. In the energy area, interaction by technology developers with energy companies and operators of the energy infrastructure is often an important type of interactions, as the integration of new innovations in established energy systems is a central issue. The synergies that result from the knowledge interaction between actors are often of critical importance to the competitive strength of an area.

Together the indicators illuminate whether there is a kind of efficiency of the interactive learning in the innovation systems. There is not one universal, best structure of innovation systems and thus no single indicator that is superior in general to all other indicators.

It is important to note, that some of the indicators of competitiveness clearly can be seen as strategic indicators, not only pointing to the current competitiveness on existing markets and within existing product categories, but to the innovative capabilities and the potentials of the industry to be competitive in the future. They illuminate to which extent the industry field in case has the competences for making changes in the future. Moreover, they can also point out lacking functions or weak elements that can be critical for the competitiveness in the future.

Governmental R&D expenditures are also one of the indirect indicators for competitiveness. Though this can be important in many cases, there is no linear connection between governmental R&D expenditures on an area and its' competitiveness. With the considerable emphasis on formalised knowledge production and formalised experience gathering there traditionally is in governmental R&D expenditures, this indicator type must be considered usually a third order indicator of competitiveness rather than a second order indicator. Therefore governmental R&D expenditures are an example of an indicator type for which it is very important to consider the indications in connection with other indicators and, more generally how the knowledge development in the public R&D activities connects to and are integrated with other kinds of learning activities.

Indicators for competitiveness

Export

Europe is a net importer of energy (which related to the safety-of-supply issue) but a net exporter of energy technologies. According to an analysis by the Danish Energy Authority and Statistics Denmark the export out of the EU (extra EU-15) of energy technology and energy equipment has increased from 42.2 bn€ in 1996 to 92.6bn€ in 2006. The import (extra EU-15) has in the same period increased from 20.9 to 47.3 bn€. This leaves EU-15 with a net export of energy technology in the order of 45.5 bn€ in 2006[3]. Germany accounted for approximately 40% of the EU-15 total, and Italy is the second biggest exporter. Energy technologies in average accounted for a little more than 5 % of the total export of the EU-15 countries (including mutual trade). See fig. 1. For countries as Italy and Denmark energy technologies amounts to almost 8% of the total export. For Denmark the export of oil and gas amounts to a similar percentage. Furthermore, both Denmark and Italy have experienced a significant growth in the export of energy technologies in the period 2004-2005. In the other end of the scale is Ireland with the very low export of energy technologies and even a declining rate during 2004-05. Also Belgium/Luxembourg, Spain and Portugal seem to fall further behind the EU average. On the other hand the Netherlands and partly the UK are catching up. No data are yet available on the distribution of this export over different energy technologies.

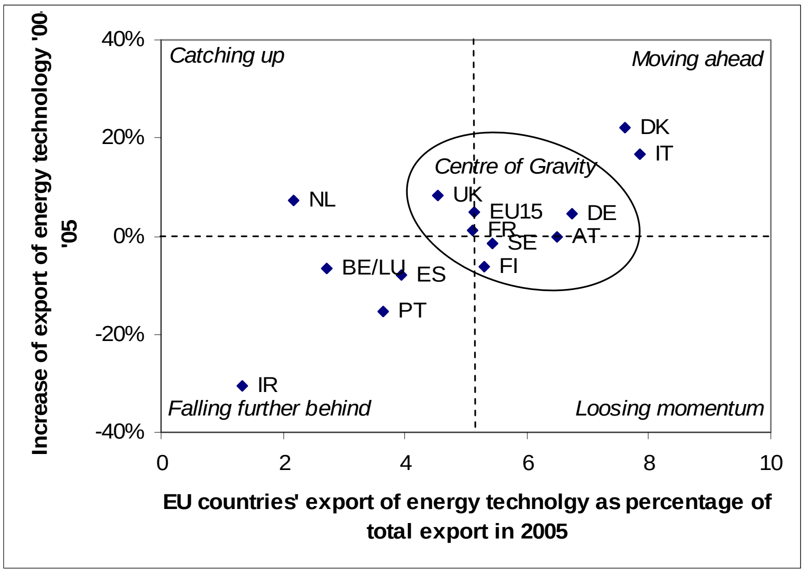

Figure 1. EU countries' export of energy technology (% of total export) in 2005 and the relative change (in % of energy technology export) during 2000-05. Source: Dannemand Andersen (2007) based on data from Danish Energy Authority and Statistics Denmark.

Market shares

Individual firms and countries market share is also an indicator of competitiveness. Trade literature often lists top-10 firms with in a certain technology and the country of their main presence. A variety of consultancies provides annual updates on markets and industrial development for most new energy technologies. The consultancy BTM Consult provides an Annual Market Update for Wind Power and Johnson Matthey plc provides an annual Fuel Cell Today Worldwide Survey[4]. In table 1 is depicted such a list for wind turbines. As the table indicates European wind turbine suppliers seems very competitive, but with large differences. Firms such as Vestas and Siemens produce almost solely for a global

[3] Data made available from Danish Energy Authority and Statistics Denmark, 2007.
[4] See: www.btm.dk and www.fuelcelltoday.com

market whereas smaller firms such the Spanish firm Acciona and the Indian firm Suzlon have a very limited presence on the world market.

Firm name	Country of main presence	Market share in 2006 in MW	Market share in 2006 in %	Export in 2006 in MW	Export share in 2006 of total production
Vestas	Denmark	4339	28.2	4228	99.7
Gamesa	Spain	2346	15.6	1385	59.0
GE Wind	US	2326	15.5	1205	51.8
Enercon	Germany	2316	15.4	1461	63.1
Suzlon	India	1157	7.7	227	19.7
Siemens	Denmark	1103	7.3	1103	100.0
Nordex	Germany	505	3.4	400	79.1
Repower	Germany	480	3.2	281	58.5
Acciona	Spain	426	2.8	53	12.3
Goldwind	P. R. China	416	2.8	0	0
Others		689	4.6		
Total		16006	107		

Table 1. Market shares of 10 leading wind turbine suppliers. Source: BTM Consult, 2007. For technical reasons (explained in the source) the totals amounts to more than 100%.

A problem here is of course the increasing internationalization of industrial production making it difficult to define nationality of large firms. The firm Nordex started out as a Danish family owned firm, but is today a controlled by German interests with manufacturing two places in Germany and subsidiaries in several countries. Another issue relates to the sub-suppliers, as these often not are included in statistics. One of the industry's leading supplier of gearboxes, the Belgian based Hansen Transmissions International NV, (that by way in 2006 way purchased by the Indian firm Suzlon) do not appear in the lists of wind turbine suppliers. In the latest reported financial year (2004/2005) the firm had a turnover of over 210 million euros, and employed a staff of 1100 worldwide[5].

Share prices

A related indicator is the development of share prices at the stock market. Share prices reflect maybe more the market expectation to future competitiveness than competitiveness today. Wind turbines manufacturers such as Vestas Wind System A/S (Denmark), Suzlon (India), Nordex AG (Germany) and Gamesa Eolica (Spain) are independently listed at international or national stock exchanges. Other firms such as GE Wind (USA) and Siemens Wind Power (Denmark and Germany) are fully owned subsidiaries of large engineering conglomerates and their performance and competitiveness within the wind power sector is overshadowed by these conglomerates general performance. For privately owned firms or firms with no publicly traded shares such as Enercon GmbH (Germany) share prices are also difficult to estimate.

Job creation

As job creation is high on the political agenda in many countries several energy technology actions plans and roadmaps have considered employment effects of increased use of the technology in quest. As an example the European Wind Energy Association that expects that up to 368,000 jobs will be created in the EU between 2000 and 2020 assuming that wind power is expanded to provide 15% of the Unions demand for electrical power by 2020. Other industry organizations have put up similar figures. From a macro economical

[5] Press release from Hansen Transmissions: http://www.hansentransmissions.net/news/suzlon.htm

point of view job creation is not in it self an aim for governmental science and innovation policy. Macro economists put more focus on improvements of the productivity of a sector or a nation.

Innovation System Indicators

In the context of the European Environmental Technologies Action Plan (EU ETAP) a variety of investigations have been carried out on the concept of "eco-innovation" and indicators for this[6]. From the definition of an innovation system that it is about

1) Knowledge creation
    a. Governmental R&D expenditures
    b. Private R&D expenditures
    c. Publications, citations and patents
2) Actors (industry, markets, institutions)
    a. Venture capital and IPO Value
    b. Markets size and market growth rates
3) Actors' mutual interaction
    a. Co-authoring and co-patenting
    b. Joint R&D - participation in governmental (or international) R&D programmes
    c. Tech-trans schemes

Governmental R&D expenditures

Governmental expenditures for energy related research and development within an area of energy technology. Government's expenditures can be found in IEA Energy Technology R&D Statistics that is based on information from the individual IEA member countries[7]. The quality of this data can be questioned but it is the best available today. For most energy technologies data are available since the 1970s. For several newer energy technologies such as fuel cells and hydrogen, data have only been included since 2004. An important note is that only OECD/IEA members contribute to this statistics. Countries such as China, India, Russia and Brazil are not included in the figures. Especially, within the recent years quite an effort has been made in energy related R&D in these countries. In figure 2 governmental R&D expenditures for wind energy in the period 1996-2005 are used.

Private R&D expenditures

Several studies have tried to assess private sector (firms') expenditures on energy related research and development, but accessibility of comparable data is usually a prohibitive fact. One such study is the EU FW6 project SRS NET & EEE (Scientific Reference System on new energy technologies, energy end-use efficiency, and energy RTD). As the project is ongoing no results are yet available.

Publications, citations and patents

The number of publications and citations within an area of energy technology can be extracted from different databases. Such bibliometrics is an easy accessible and well described (and often criticized) indicator. Patents are also a relatively accessible indicator. But common for both bibliometrics and patents data are the problem of defining search words. Experts from the field of science and technology in quest must be involved in the process of defining adequate search words. Bibliometric searches are usually carried out in

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[6] Andersen, M. M.: Eco-Innovation Indicators. European Environment Agency, Copenhagen, February 2006.

[7] On-line access via: http://www.iea.org/Textbase/stats/rd.asp

Science Citation Index and Derwent World Patents Index. Both of which are hosted online via STN International. In figure 2 indicators for wind power the following search words was used:

- Science citation index: wind power(5w)plant? or wind(5w) turbine?
- Derwent world patents index: wind power(5w)plant? or wind(5w) turbine?

Values comprises a time span of 1996-2006.

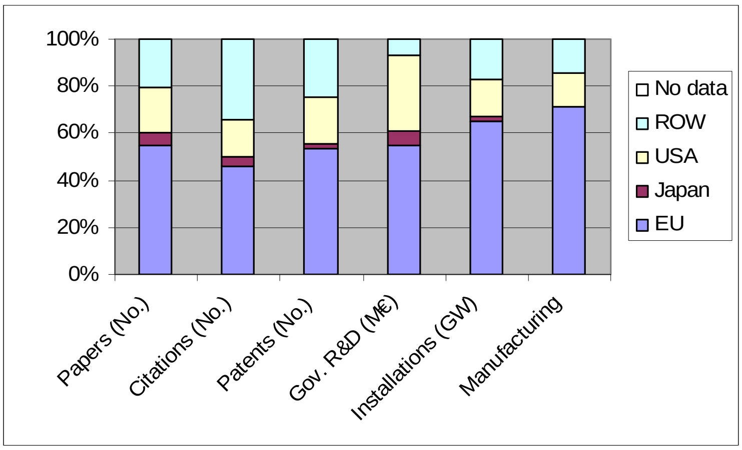
Venture capital and IPO Value

Venture capital attracted to an area of technology is also an interesting indicator, but again accessibility of comparable data is a problem. A recent report from the consultancy New Energy Finance has analysed issues such as venture capital, private equity, incubators and investments funds in the area of sustainable energy[8]. The IPO value in the energy technology area boomed in 2006 with an increased on 156% measured on global level[9]. Solar energy and bio fuels are the primary driving areas in this (Lux Research 2007). In Denmark, the venture capital investments in renewable energy and other eco-innovation areas has developed from being almost invisible in the general picture of the venture area in the late 1990s to accounting for 7% of the investments in 2006 (Vækstfonden 2007). Venture capital and IPO value might also count as indicator for firms' or sectors competitiveness or at least as the markets expectation for future competitiveness.

Markets size and market growth rates

Regarding markets several indicators are mentioned in literature, but in this context we will focus on only one indicator: Market size and market growth rates. For most energy producing technologies trade literature lists cumulated installations in MW and installations in most recent year. This is often a quite easy to access indicator that can be broken down on countries and regions. Markets can be broken down into two types: energy markets (e.g. bio ethanol) and technology markets (e.g. equipment or plants for producing bio ethanol). For an energy technology perspective the latter of course is the most important – provided the data is available.

In figure 2 the cumulated installed capacity in GW by the end of 2006 is used as an indicator for market sizes for wind turbines. Additional annual installations could also be used as an indicator.



[8] http://www.unep.org/pdf/SEFI_report-GlobalTrendsInSustainableEnergyInverstment07.pdf
[9] Initial Public Offering (IPO) is the first sale of stock by a private company to the public.

Figure 2. Example of overview over indicators. Indicators for wind energy technology. Installations refer to cumulated installations of wind turbines in GW and manufacturing refers to home country of leading wind turbine manufacturers. Source: Dannemand Andersen, 2007.

Interaction between actors

Indicators for interaction between actors are difficult to find within traditional statistical accounts. Concerning knowledge production and bibliometric indicators such as co-authoring and co-patenting in the future might be developed as useful tools. Useful information about joint (science and industry) research projects can be drawn from databases over projects within public R&D programmes (e.g. EU Framework programmes or national programmes).

The table below is an example of some of the results from an investigation of this in Danish energy R&D programmes. It shows that there are significant differences in the patterns of public-private co-operation within different areas of energy technology. A considerable larger share of projects in the wind energy area than in the area hydrogen technology includes co-operation between industrial companies and public research institutions. However, there is a larger share of other kind of public-private co-operation in the hydrogen area than in the wind area. This can e.g. be joint projects between private technology developers and regional authorities.

	Co-operation btw. business and public research	Other public-private co-operation	Other co-operation across actor types	Total (N)
Hydrogen	36%	16%	9%	44
Wind	57%	2%	15%	46

Table 2: Share of projects within the national energy R&D programmes that involves co-operation between actors of different types. The last column includes e.g. co-operation public-public co-operation between local authorities and research institutions and private-private co-operation between industrial manufacturers and consultancy companies (Borup et al., 2007).

A more general picture of the patterns of interaction between actors can for example be found through questionnaire surveys or telephone interviews with the actors involved in energy area. Here one will also be able to find significant differences between the interaction patterns in different energy technology areas. For example, Figure 2 shows which kinds of partners the actors collaborates with in the area of wind power in Denmark. It indicates that private customers and suppliers and sub-suppliers of energy technology and components are the most significant collaboration partners, while e.g. public authorities and public research institutions (‘universities’) have less emphasis, also if one compare with the areas of bio energy and hydrogen technology that on these two parameters show figures around 60-80%.

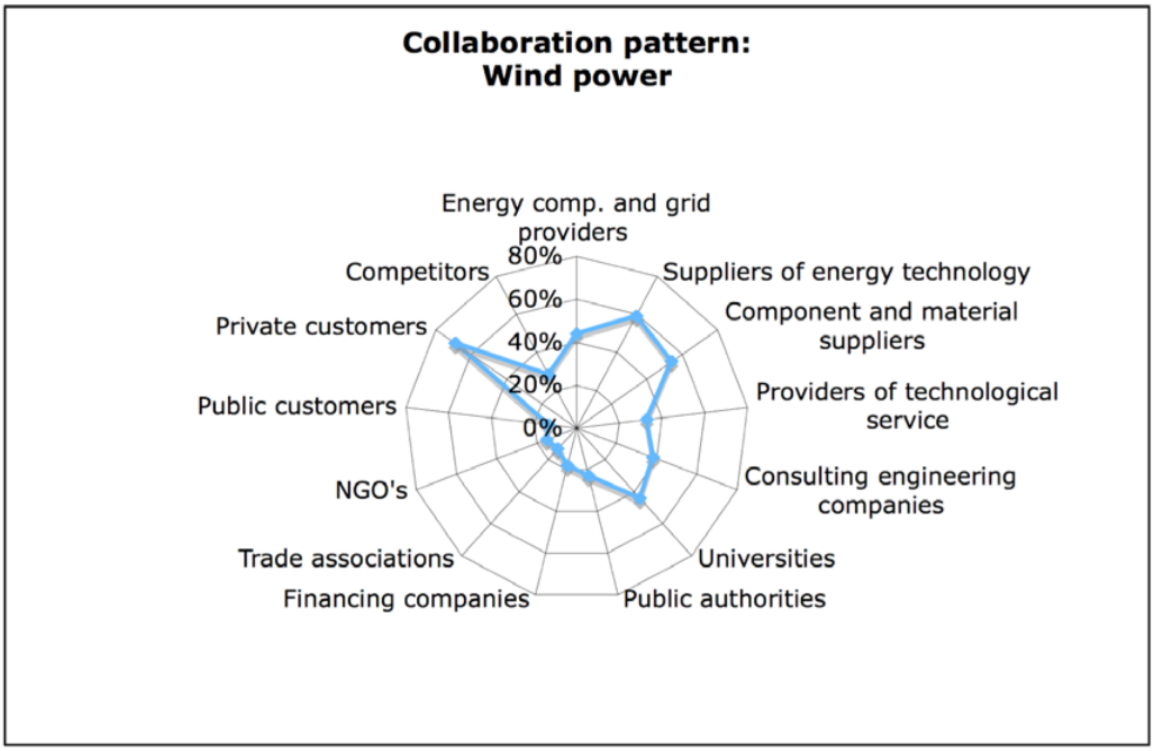


Figure 2: Collaboration pattern in the area of wind energy in Denmark (Borup et al., 2007).

The examples above cover formalised co-operation. Many qualitative analyses show that informal co-operation and discussions in networks, and larger or smaller debate forums are very important for innovation. This can however be quite difficult to cover fully by quantitative indicators, though questionnaires and interview surveys to the actors in the field can investigate the issue to some extent. Indicators that cover broad debates and public discussions can build on media analyses and on surveys among the general public.

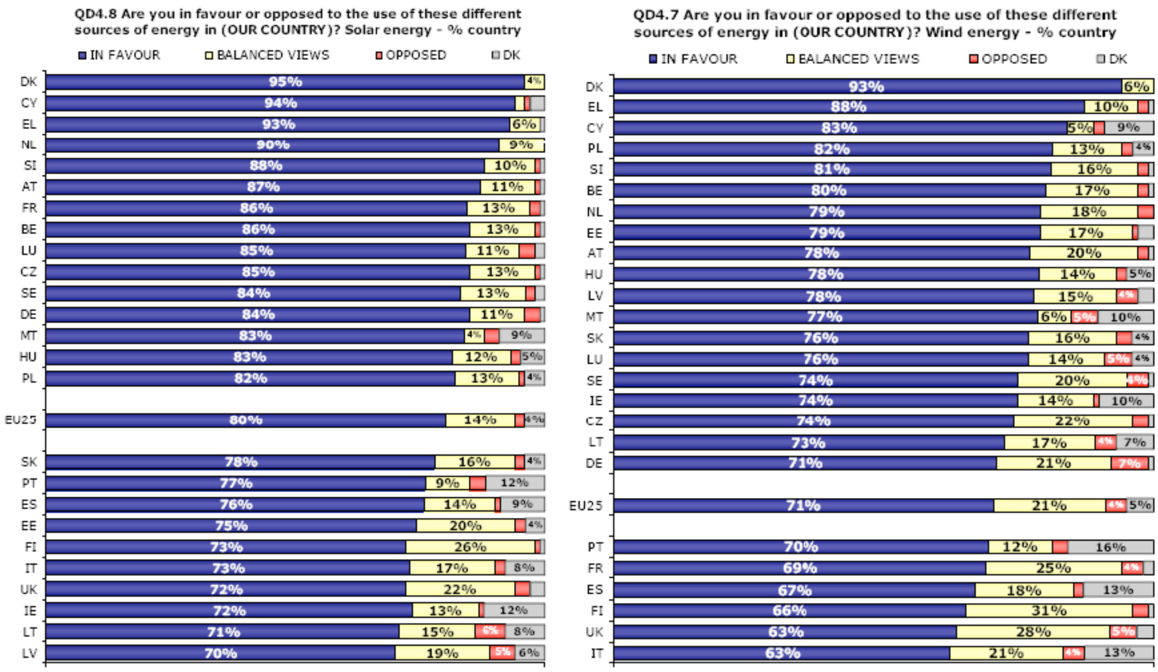
An example of this is shown below. Here it can be seen that there in the area of renewable energy technologies is relatively large awareness and support in the broad public in Denmark compared to many other European countries.

There is no reason to believe that eco-innovation happens through completely other development dynamics than other kinds of innovation. Still, eco-innovation differs from traditional innovation by having environmental issues and sustainability higher on the agenda in larger or smaller parts of the innovation activities. A set of indicators for eco-innovation must, in order to be useful, be sensitive to this eco dimension of eco-innovation. Where does that come into the picture? Following the innovation system approach especially two places can be pointed out[10]: First, in the formation of markets, where e.g. market demands and constructions and regulations of markets can reflect the issues. Second, in the 'guidance' of innovation activities. This consists in the visions and expectations that influence and give direction to innovation activities including both formal strategies and policy developments at different levels as well as, partly tacit, goal-setting and problem definition within e.g. knowledge communities or among development

[10] We here build on the technology-oriented innovation system approach and the seven overall functions in innovation systems it describes (Jacobsson & Bergek 2004, Hekkert et.al. 2006).

engineers in industrial companies. The market signals are of course often a part of the guidance of innovation.

Figure 3: Public opinions on selected energy technologies (source: EU 2007, Eurobarometer)



Technology transfer is also a good indicator for knowledge creation especially from a innovation systems perspective. Here Bozeman and others have developed what they call “contingent effectiveness model of technology transfer”(Bozeman, 2000; Bozeman & Fellows, 1988; Bozeman & Crow, 1998). In this model they have identified different dimensions that influence the diffusion of knowledge in the society, which give an evaluation of how good a technology transfer works. The dimensions are: transfer agent, transfer medium, transfer object, transfer recipient and demand environment.

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